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6. AUTHOR(S)

David A. Swinney & Edward E. Smith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Graduate School and University Center
of the City University of New York
33 W. 42nd ST , box 655
NY, NY 10036-8099

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NL
Building 410
Bolling AFB DC 20332-6448
Dr. Tangney

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The goal of this work is to detail the temporal course of information integration during plausible reasoning, with a focus on: 1) the component processes in terms of their time-courses and information content; 2) the degree to which reasoning consists of "modular" (autonomous, independent, informationally encapsulated) stages of processing; and 3) how components of reasoning are drawn together to eventuate in a single answer to a reasoning problem . The first year of this work has involved three relevant lines of inquiry: 1) Conceptual Combination. The set of studies in this area demonstrated that claims by Springer and Murphy (1992) to the effect that conceptual combination takes place such that initial components of the combination are not activated and processed separately, are not supported. 2) Reasoning and Categorization. These studies have demonstrated that evidence from Rips (1989) that categorization can take place based on reasoning as well as on similarity, seems to be true, but only under conditions where the informational basis for categorization is quite sparse and when the subject is aware that his/her basis for the categorization must be defended. 3) Modularity and Discourse Finally, a claim by Marslen-Wilson and Tyler (1987) purporting to demonstrate an important lack of modularity of processing during discourse/sentence comprehension was examined in detail utilizing a more sensitive task than they employed. With the use of this technique, it was demonstrated that modularity between semantic and syntactic information was maintained during this (particularly critical) stage of language processing.

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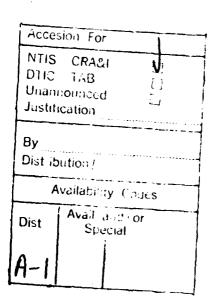| **17. SECURITY CLASSIFICATION OF REPORT** (U)	**18. SECURITY CLASSIFICATION OF THIS PAGE** (U)	**19. SECURITY CLASSIFICATION OF ABSTRACT** (U)	**20. LIMITATION OF ABSTRACT** (U)

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Temporal and Qualitative Decomposition of Plausible Reasoning

David A. Swinney
City University of New York Graduate Center
Psychology and Linguistics -rm. 1422
33 W. 42nd St
New York, N.Y.   10036
            and
Edward E. Smith
Department of Psychology
University of Michigan
Ann Arbor, Mi.

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The overall goal of our work is to detail the temporal course of information integration as it takes place during plausible reasoning, with a focus on determining: 1) the component processes in terms of their time-courses and information content; 2) the degree to which stages of reasoning represent "modular" (autonomous, independent, informationally encapsulated) stages of processing (as compared to a totally "interactive" system); and 3) how various putative components of reasoning are drawn together to eventuate in a single answer to a reasoning problem . The initial work (in this first year) of the grant has involved the pursuit of three particular lines of inquiry, in consonance with these goals.

1. Conceptual Combination

The first of these focused on the examination of the temporal course of processing during conceptual combination. Our first three studies were based on examination of recent claims by Springer and Murphy (1992) that conceptual combination takes place in a totally interactive fashion. The reason for starting with their work is that their argument that there are no (initial) "independent" stages of literal processing that precede the conceptual combination of information, invalidates the basic premise of much of our proposed work in this area (namely, that there *are* independent components in conceptual combination at some (early) point in processing that each contribute individually in conceptual combination.)

In Springer and Murphy's experiments, subjects were required to make true/false decisions to phrases such as: "Peeled Apples are 'X' ", (where 'X' was either a common 'literal' property of the noun (Apple) such as 'RED' or a so called 'emergent' property of the adjective-noun combination (Peeled Apple) such as 'WHITE'. This emergent property was intended to be one that was not a part of the normal property list for either the adjective or noun by itself, but only one which "emerged" from the combination of these items. (There were 2 other conditions in their experiment, but they are not relevant to the focus of our work and this discussion). They reported finding that verification of such "emergent" properties was as rapid as that for 'literal' properties, and concluded that these emergent properties were made available immediately (interactively) and that there was no stage in which the 'literal' properties of the noun (or adjective) alone were first made available, prior to the activation of 'emergent' properties. This conclusion is quite contrary to our basic research hypothesis, and it seemed a critical place to begin our research. A fundamental reason to doubt the conclusions of Springer and Murphy resides, in the first instance, in the observation that the dependent measure they used (an end-of-sentence verification task) is 'off-line", in that it examines the categorical-combination process only well <u>after</u> it has been completed. Thus, it seemed likely to us that an 'on-line' test of categorical combination -- one that examined activation of meaning while the words were being processed -- might reveal that adjectives and nouns

combine in a manner that is far more intricate than revealed by Springer and Murphy's "off-line" examinations.

Our initial experiment used the 20 Springer and Murphy experimental items (which they kindly provided to us) , along with 40 additional items that we constructed along similar lines as their items, in a speeded reaction time procedure. In this procedure, subjects were presented visually with , first, an '*' (to get the subject's attention), followed by a presentation for 1000 msecs of the adjective-noun pair ('PEELED APPLE') followed 100 milliseconds later with a single word which the subjects had to 'name aloud'. This word was either a property of the noun alone ('RED') or an "emergent" property of the adjective-noun pairing ('WHITE'), or a control word for each of these probes (control words were matched for frequency, length, and naming time with the property-probe words, but were unrelated to either the noun or the adj.-noun combination). Subjects were required to "name" these word aloud as rapidly as possible. The principle behind use of this task rests on the semantic-priming effect; if a property of either APPLE or PEELED APPLE has been activated by the time the property word (RED or WHITE) is displayed for naming, it will 'prime' or facilitate such naming, as compared to naming of the unrelated control word. We anticipated that 1000 msecs of processing time was more than sufficient for the 'emergent' property to be activated from the adjective-noun combination, and thus we predicted that results from this initial experiment would , in a sense, replicate the results of Springer and Murphy -- that is, that both RED and WHITE would be 'primed' if the subjects had more-than-sufficient time (1000 msecs) to process the material and reflect on it.

The initial results were in accord with this prediction. Both the word related to the noun alone (e.g., RED) and that related to the the "emergent" property of the conceptual combination (e.g., WHITE)- were facilitated relative to their controls in this experiment. This, then, roughly replicated the Springer and Murphy findings, but with a slightly different test format. Thus, given enough time, it appears that both the noun and the "emergent" properties are both available(activated). The critical question concerned whether there are different time-courses of availability for these two "meanings", and whether, if one tests closer to the point at which these words are just initially being processed, it might be discovered that the noun meaning alone is activated (accessed) before that for the conjoint meaning for the adjective -noun combination.

Thus, in the second experiment of this set, we presented the combined adjective-noun pair(e.g., PEELED APPLE) for a shorter display time (400 msecs) before presentation of the property-probe (or control) word. Pilot work indicated to us that 400 msec was sufficient time to just barely be able to read both words, on average. Thus, we reasoned that not much more than initial processing of these items would have taken place in the allotted time, before the probe word was displayed. The results from this test were some what surprising: again, both the noun and the emergent property probes were facilitated relative to the control words. Upon initial consideration, it appeared that Springer and Murphy might have been correct -- that the emergent property was available as rapidly as the noun property, suggesting that there was no initial stage in which the noun and adjective properties were considered independently.

However, at this point, it was discovered that there was a serious difficulty with the "emergent" property probes used by Springer and Murphy (as well as those additional items we had created, following Springer and Murphy). It turned out that these so-called "emergent" properties were all highly related to the ADJECTIVE in the adjective-noun pair. Thus, whatever activation was being obtained for the so-called "emergent" property was potentially just activation caused by the adjective alone. In short, neither Springer and Murphy's materials, nor our extra materials provided a test of the hypothesis at all. To further substantiate this hypothesis, we ran a ratings test in which we asked subjects to rate how related each word (the Adjective alone and the Noun alone) of the combination, and the combination itself, was to the "emergent" property probe. 14 of the 20 items used by Springer and Murphy were judged to have a strong -to- very strong relationship to the "emergent" probes (on a 7-point scale ranging from no-relationship to very-strong relationship). Interestingly, only 18 of 20 of the adjective-noun combinations used by Springer and Murphy were judged to have an equally strong relationship to the "emergent" probe. Thus, in only 5 of the original Murphy and Springer materials were there any true "emergent" properties present (Note that the examples provided in the published Springer and Murphy paper ("peeled- apples and boiled celery) constitute 2 of these 5 items). A similar ratio existed for the materials we created to extend their items. Unfortunately, there were too few items containing any true "emergent" properties to do meaningful statistical tests. Thus, it was necessary to develop new materials to examine the Springer and Murphy claims.

Experiment 3 is currently ongoing with a set of 44 items which were obtained by asking subjects to provide properties for 72 items which we judged to contain true emergent properties. The 44 items chosen for the experiment were done so on the basis of neither the adjective nor the noun having any listing of the "emergent" property by 40 subjects in this pre-test. Currently, the chosen 44 items are being tested with the relatedness-ratings procedure (as was done the Springer and Murphy items) to make certain that the emergent properties are truly NOT part of the adjective or noun by itself. This work will be completed by the end of June, 1992, and immediately thereafter the first 2 experimental conditions (with the 1000 msec and 4000 msec presentations of the adjective-noun pair) used in experiments 1 and 2, respectively, will be run on these new materials.

Simultaneously, the new items gathered will be used in a slightly different experimental design - one involving the auditory presentation of these adjective-noun combinations embedded in sentences. (Experiment 4). The motivation for this is two-fold. First, and most important, there is a large array of subtle evidence suggesting that the processing of words "in language" (i.e. in ongoing language processing) is considerably different than that found in isolated presentation of words or word pairs (or triplets, etc.). Thus, considering that much of conceptual combination occurs (in real-life) in actual conversation or reading, we will examine the temporal course of component processes of conceptual combination in a sentence-comprehension framework as well as in the word-pair visual framework (as discussed above). The second motivation for this move is to allow the use of cross-modal lexical priming. This technique, which allows presentation of probes (and the study of priming at any time during hearing of the words in a sentence, allows for temporal

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precision in the testing of activation of adjective and noun meanings, as well as emergent property meanings. (This is so in that , with auditory presentation, one can know precisely when the relevant information has been heard and processed. In visual presentation involving more than one word, it is difficult to tell precisely what point the listener has reached at any particular time during the processing of various words).

2. Reasoning and Categorization

A second line of research which we have undertaken concerns the idea that there are two kinds of categorization, corresponding to whether categorization is based on similarity or reasoning. The principle behind this work is that the basis for when similarity or reasoning are employed in categorization has to do, at least partially, with the amount of time that has transpired during processing. Our empirical work here is based primarily on a prior study by Rips (1989) . On each trial of Rips' experiment, subjects were presented with a description of an object that mentioned a single value on a single dimension (e.g., an object's diameter), and were required to decide which of two categories the object belonged to (where the value given was in the middle of the subject's estimated value of that dimension for each of the two concepts; these values were collected from each subject on each trial before the "mean" value of the dimension was provided to them for the categorization). For example, In Rips experiment, each subject was asked to provide the average size (diameter) of a quarter and of a pizza. The, subjects were asked to categorize an item as either a PIZZA or a QUARTER when that item was "an object 3 inches in diameter" (where 3 inches was the mean of the subject's estimate of diameter for a quarter and a pizza) In this study, subjects judged the item more likely to be a pizza than a quarter, even though it had previously been demonstrated that the object was considered more similar to a quarter than a pizza. In cases like this, it appeared that categorization is not based on similarity and instead presumably reflects a reasoning process (where the reasoning is based on the fact that the size of a quarter is constrained).

In our studies, (carried out in conjunction with Dr. Steve Sloman, a post doctoral student at Michigan) we have tried to determine what factors lead to reasoning-based categorization versus similarity-based categorization. One factor we have explored is the sparsity of the information given about the object to be categorized. In Rips' experiment, this information was very sparse. In our 3 studies thus far, we have varied the sparsity of the information provided to the subject and the manner of presentation of that information. The first experiment involved presenting the Rips information (the Sparse condition) and a condition in which subjects were given extra information (the Rich condition). For example, the sparse conditions for the Quarter- Pizza example would involve telling the subject that the object was "3 inches in diameter". The rich condition would involve telling the subject that the object was " 3 inches in diameter and a shiny silver color". Thus, in the rich condition, one piece of "typical" information was added. The results indicate that when the object description is relatively rich subjects make their categorizations on the basis of similarity (i.e.- similarity to typical information). However, when the information is Sparse, the Rips effect is

replicated, in that categorization is based on reasoning. This suggested to us that reasoning-based categorization may be what people do when the information is impoverished.

The second set of experiment in this area involved obtaining the protocol information (judgments as to size, etc. of each object in the experiment) at the beginning of the experiment for all item, rather than just before each trial. In these cases, Ss' categorization was based largely on similarity (typicality) in both the sparse and rich conditions. Relatedly, there was a hint of a speed-up in response time under these conditions. Thus, it may be that subjects forget their own estimates over time and the basis for categorization reverts from reasoning to similarity. Overall, it appears that rapid categorization, and the more general cases of categorization appear to be based on similarity. It appears that, in order to obtain theory-based (reasoning-based) categorization, conditions have to be such that the subject is aware that he/she may have to defend his/her decision (as might occur when protocols and judgments occur on the same trial, with sparse information available).

Research in this area is proceeding with work on speeded processing and delayed processing to determine more precisely when reasoning is and can be drawn into the categorization process.

3. Temporal decomposition and modularity during discourse processing

One important aspect of the current grant was the investigation of whether there are isolable, independent stages of reasoning that are driven purely by the initial stages of perceptual (form) input and not by "top-down" (world knowledge) information. A major motivation for this work has been the general assumption of most research in the field of reasoning that "reasoning" has access to "general (world) knowledge", and, thus that it is not comprised of modular subprocesses. This general assumption was, at one time, also held for work in natural language processing. However, careful, on-line (real-time) study of natural language processing has demonstrated that, in certain stages, language processing appears be highly modular. Examination of the current literature on plausible reasoning suggested that the general assumption of non-modularity for reasoning was likely a mistaken one, but that the only way to discover the nature of such processing was by the application of "real-time" experimental techniques -- techniques that reflect moment-by-moment processes that occur *during* such reasoning, i.e., in "real-time"-- to conditions of reasoning.

Given that the only current support for modularity of processing, as demonstrated through temporal decomposition techniques, lies in various areas of language processing, it was felt to be important that some examination on this grant be made of recent claims that purport to dispute the findings of modularity in language processing; if there is no such modularity in language processing, that lessens considerably one premise of this grant - namely, that such modularity will also be found in plausible reasoning.

Thus, our third line of research examined carefully the role of discourse information in "predicting" the grammatical role of potential referential antecedents. This work (carried out in conjunction

with Dr.'s Jerry Fodor and Merrill Garrett) examined a claim by Dr. William Marslen-Wilson and Dr. Lorraine Tyler(1982) of a case demonstrating an apparent interactive (anti-modular) effect in discourse processing. Their work provides what is perhaps the most striking current support for the interactionist view of parsing.

Subjects in their experiment heard discourses followed by related sentence fragments. For example, a typical stimulus might be:

> *"As Philip was walking back from the shop, he saw an old woman trip and fall flat on*
> *her face in the street. She seemed unable to get up again. Running towards..."*

Immediately at the end of the sentence fragment, a visual target for a naming task was displayed; one subject group received the target 'him', and the comparison group received the target 'her'. The targets were always anaphoric pronouns.

The question of interest involved the interpretation of the gerundive expression 'running'. Notice, in the first place, that this is understood as having an implicit subject. It is reasonable to suppose that supplying this subject is part of the hearer's task in understanding the sentence. Second, notice that so far as the *syntactical* structure of the discourse is concerned, the implicit subject could be either *Philip* or *the old woman*. What tells the hearer who it was that did the running is the interaction of semantic information in the discourse context with his real-world knowledge. That is, given the discourse information that the old woman fell down, and the real-world information that old women who have fallen down are unlikely to be up and running in the next sentence, the listener can infer that it is "Philip," rather than "the old woman" that is the implicit subject of "running". The experimental question is whether the listener assigns subjects to gerunds by making such extralinguistic inferences on line (immediately). Evidence that the listener does so would tell strongly in favor of the claim that syntactic and semantic information interact (are not modular) in parsing.

Suppose, consonant with the interactive account, that by the time the subject reaches the end of the sentence fragment (hence at some time prior to the presentation of the naming target) he has made the context-based inference that 'Philip' is the subject of 'running'. Now consider the two experimental conditions. If the target is 'her,' the gender marking of the pronoun requires that its antecedent in the discourse must be 'the old woman'. This assignment is compatible with the contextual bias for taking 'Philip' to be the subject of 'running,' and the performance of the naming task can proceed smoothly. If, however, the target is 'him', then there is a conflict with the contextual bias. For one thing, if 'him' is assigned as the object of 'running towards' in a sentence where 'Philip' has already been assigned as its subject, then the speaker is represented as saying that Philip is running towards Philip, which seems hardly plausible. Moreover, this analysis would make the sentence ungrammatical since if 'Philip' is both the subject and the object of 'running towards,' the target pronoun ought to be reflexive.

In short, the naming response to 'him' as target should be inhibited if the discourse context has been used to infer the subject of 'running towards' as the interactionist account of parsing requires. It, on the other hand, no such contextually based inference has been made by the time the target is presented, then there is no reason why reaction times for the 'him' targets should differ from those for the 'her' targets. In short, the modular parser predicts no difference between the targets; the interactionist parser predicts that the response times for 'him' will be longer than those for 'her'. In Marslen-Wilson Tyler's experiment, the observed reaction times favor the interactionist prediction.

We tested the predictions of the interactive account of gerundive phrase parsing by using a cross-modal priming (CMP) task with reaction times for naming responses as the dependent measure. (Variants of this technique have been applied in several studies of sentence processing (e.g., Swinney, Onifer, Prather and Hirshkowitz, 1979), lexical ambiguity (e.g., Tanenhaus, Leiman and Seidenberg, 1979; Swinney, 1979) and, more recently, of pronoun and empty category interpretation (see, e.g., Nicol and Swinney, 1990 for a review)). The task is similar to the one used by Marslen-Wilson and Tyler in that the sentence stimuli are auditory and the naming targets are visual. But the experimental techniques differ markedly in that the CMP task does not require the subject to integrate the visual probe into the structure of the stimulus sentence, nor does it require the subject to respond to sentence fragments.

In our variant of the CMP methodology, subjects listen to tape recorded test sentences while watching a CRT display; at various points during the auditory presentation of the sentence, naming targets appear on the CRT screen. Reaction times for naming targets that had previously occurred in the sentence (i.e. in the auditory channel) are compared with reaction times for otherwise similar control targets that had not. The application of the method to the present materials relies on the following assumption: when an anaphoric element is assigned a discourse antecedent, semantic (and other) information about the antecedent becomes active at, or very shortly after, the occurrence of the anaphoric element. In the present case, it is assumed that this reactivated information is then available to mediate repetition priming. There exists extensive evidence in support of this assumption (e.g., Bever and McElree ,1988; Nicol and Swinney, 1989; Garnsey, Tanenhaus. and Chapman, 1989; Fodor, 1989; Tanenhaus, Boland, Garnsey, and Carlson, 1989) . Thus, for example, naming of the visual target 'Philip' should be primed when it occurs near 'he' (e.g., at the point marked by '*') in a discourse such as:

"As Philip was walking back from the shop he saw an old lady trip and fall flat on her face in the street. She seemed unable to get up again . He * ran rapidly toward her and carefully helped her to her feet."

Notice that the prediction that there will be priming for 'Philip' at the * position in this discourse is compatible with assuming that the process of binding the anaphoric pronoun does *not* access semantic information in the discourse. This is because. Since 'Philip' is the only discourse NP that agrees with the pronoun in gender, the assignment of `Philip' as the pronoun's antecedent can be syntactically determined.

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The question of primary interest is whether comparable priming would be found at or near the word "Running" in a variant of this discourse where the sentence containing the probed position starts with a gerundive; that is a sentence that *lacks* an overt, gender marked subject pronoun. For example:

*"Running * rapidly toward her and ..."*

The occurrence of priming of 'Philip' in the * position of this discourse would imply that *semantic/pragmatic* information about the context has been used to determine the *syntactic* subject of the gerund, and this would support an interactive account of the original Tyler and Marslen-Wilson results. Conversely, the failure to find early priming would support a modular picture according to which grammatical information (like gender agreement), but *not* semantic/pragmatic information, is recruited on-line to determine syntactic properties of the input.

The sentences we used were adapted from the Marslen-Wilson and Tyler experiment. Changes made were to insure that lexical co-occurrence restrictions were not available to determine the antecedents of the pronoun targets (i.e., that there were two syntactically permissible antecedents for each target) and also that the discourse was plausible and semantically well integrated. There were 30 basic discourses used.

The pattern of results is flatly incompatible with the interactive analysis advanced by Marslen-Wilson and Tyler for the naming times for pronoun targets presented in their original experiment. The Marslen-Wilson and Tyler analysis requires that the implicit and explicit versions should show similar profiles in our experiment. In particular, it requires evidence that the contextually mandated subject of the gerund is facilitated at the position indicated by the *.

However, no indication of such facilitation is observed. Reaction times for the implicit condition are the same for both naming targets in the gerundive versions. There is thus no support for the view that the consequences of a semantic analysis of the discourse are accessible to the processes that are deployed in the parser's initial attempts to determine the values of the implicit arguments of verbs.

The results just discussed make it seem implausible that the 'missing' subjects of gerunds are recovered by the on-line exploitation of discourse information, in the manner that strong interactionist theory suggests. Rather, a modular view of processing is still supported, even here.

We suggest the following model accounts for the data we obtained (and that of Marslen-Wilson and Tyler): assignments of anaphoric referents to zero pronouns are triggered by surface features of the sentence under analysis; notably, they are triggered when the parser encounters an overt anaphoric element· So, in the case of a stimulus like the example presented above, the subject of 'crawling' is left unbound till the pronoun 'her' is encountered. Upon encountering this trigger, all NPs in the discourse are considered as candidate referents for all the anaphoric elements, both overt and covert. The assignment chosen is constrained by lexically carried information (gender, number, context restrictions, etc.) and by considerations of the overall coherence of the interpretation of the

discourse. In the overt pronoun condition, by contrast, this process is initiated as soon as the hearer encounters the subject NP 'he', so information associated with 'fireman' is available to facilitate priming at probe position indicated by the *.

Beside the suggestion that contextually based binding of implicit anaphors is delayed until triggers are encountered (rather than occurring on line), the aspect of this account that is of primary relevance to the modularity issues is the suggestion that triggers automatically activate all the (grammatically relevant) possible referents in a discourse. This implies that the role of semantic/pragmatic information is restricted to post-activation filtering of the candidate assignments, a view that would comport with the general principle proposed above, that the characteristic role of extragrammatical information in parsing is to reject analyses that are grammatically licit but implausible.

Papers/presentations from this first year of work:

The work described in section 2 is being written for publication at this time. It will be a paper co-authored by Dr. Steve Sloman and Dr. Edward Smith. It is expected to be submitted in the Fall, 1992.

The work described in section 3 has been submitted for publication on June 15, 1992:

Fodor, J.A., Garrett, M. and Swinney, D.A. . A modular effect in parsing. under review The Journal of Language and Cognitive Processes.

It has been presented at the Conference on Sentence Processing, New York, 1992, by Dr. Swinney

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